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Principles of Heating and Refrigeration

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Model: All

Production: All

OBJECTIVES

After completion of this module you will be able to:

- Describe the difference between a HVAC system and a Climate Control System.
- Describe the meaning of the “Comfort Zone”.
- Identify the principles of Heating and Refrigeration.

Heating Ventilation Refrigeration (HVAC)

The purpose of the heating, ventilation and air conditioning system is to treat the air entering the passenger compartment in order to achieve and maintain a constantly comfortable environment for the occupants.

This is achieved by:

- Heating or cooling the area depending on the requirements or demands of the driver / passenger and dictated by outside temperatures.
- Circulating air through out the vehicle.
- Removing moisture, to assist in defogging of the windows and enhancing occupant comfort level.
- Filtering the air to remove dust, allergens.

The modern automotive system that cools, heats, dehumidifies, ventilates and filters the air entering the passenger compartment is referred to as *Climate Control.* Climate Control describes a more complete and precise management of the basic HVAC system, where the vehicles internal climate is constantly varied and adjusted depending on the occupants desired and requested settings..

Climate Control Sub-Systems:

- Air Conditioning
- Heater
- Air Management (blower, filters, vents)
- Computer Controls

Note: Scientific investigations conducted by the World Health Organization shows that concentration and reaction diminish considerably under the effects of stress and strain.

Comfort in the Vehicle

Humans feel comfortable at a certain ambient temperature and atmospheric humidity. The feeling of well-being plays a significant part in ensuring the driver's comfort while driving. The "climate in the vehicle" has a direct influence on the driver fatigue and overall safety.

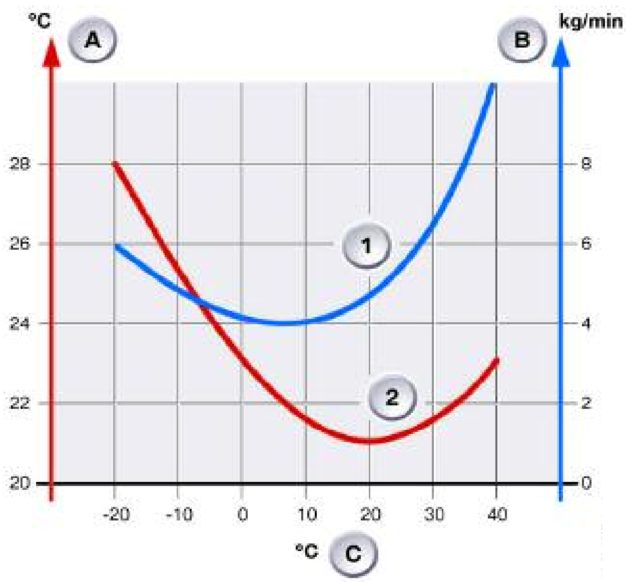
A comfortable interior temperature is determined by the prevailing outside temperature, solar radiation and adequate air output rate and circulation.

- A low outside temperature of -20°C, requires a higher interior temperature of 28°C and an air output rate of approx. 5-6 kg/min.
- A high outside temperature of 40°C, requires a low interior temperature of 23°C and an air output rate of approx. 10 kg/min.
- A moderate outside temperature of 10°C, requires a low interior temperature of 21.5°C and an air output rate of approx. 4 kg/min.

Even modern heating and ventilation systems have difficulty achieving total comfort in the vehicle interior at high outside temperatures.

- Particularly under conditions of high solar radiation (strong sunshine), the heated air in the vehicle interior can be replaced only by air at ambient temperature.
- Opening a window or sunroof or increasing the fan speed to achieve the feeling of comfort often involves draughts and other annoyances such as noise, exhaust fumes and pollen.

Comfort Curve



Index	Explanation
A	Interior temperature
B	Air delivery (vent output)
C	Outside temperature
1	Comfort curve - air output
2	Comfort curve - interior temperature

Physical strain increases by a multiple at high humidity levels.

Effects of unfavorable vehicle interior temperatures on people

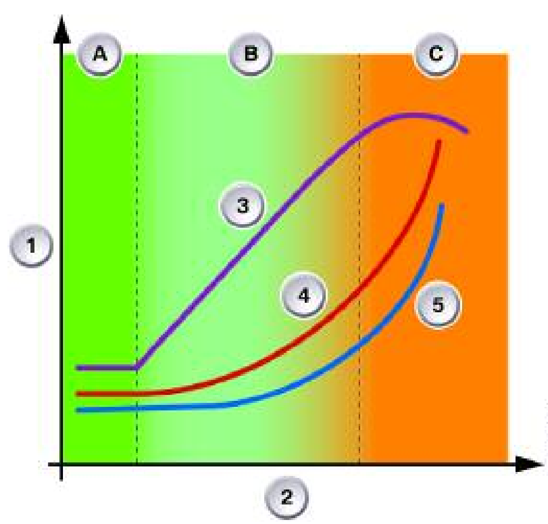
Area	With air conditioning	Without air conditioning
Head	23°C (73°F)	42°C (107°F)
Chest	24°C (75°F)	40°C (104°F)
Feet	28°C (82°F)	35°C (95°F)

Temperatures in a medium-class passenger car at: Driving time 1h, outside temperature 30°C (86°F) and sun shining (solar radiation) on the car.

Heat is a Strain

The ideal temperature for the driver is 20°C (69°F) to 22°C (72°F). This corresponds to the comfort zone A with low climatic strain:

- Intensive solar radiation (sunshine) on the vehicle can raise the interior temperature by 20°C (69°F) To 25°C (77°F) above the outside temperature, particularly in the head area where the heat is perceived as most unpleasant.
- The body temperature rises and the heart rate increases. This situation is also characterized by increase perspiration.
- The brain receives too little oxygen. Zone B is characterized by moderate climatic strain.
- Zone C poses an overload situation for the body, often referred to as "climatic stress".



Index	Explanation
1	Stress
2	Climatic Stress
3	Perspiration
4	Heart rate
5	Body temperature
A,B,C	Comfort zone

Note: Research shows that sensory perception and powers of deduction decrease by 20% at a temperature increase from 25 to 35°C (77 to 95°F)

“The Comfort Zone”

With the aim on reducing or even eliminating climatic stress situations, air conditioning systems adjust the air in the vehicle to a pleasant temperature while also cleaning and dehumidifying.

Modern climate control systems are capable of producing temperatures at the air outlets that are considerably lower than the higher outside temperatures, both when the vehicle is stationary as well as while driving.

We must keep in mind that equally important as reducing the temperature in the passenger compartment is air dehumidification. This is most effective in winter, while driving in inclement weather by controlling window condensation or fogging due to the great difference in climate between the inside and out side of the vehicle, as well in adding to passenger comfort in hot sticky weather by controlling ambient humidity. The reason for this is that the human body cools itself by allowing moisture on the skin to evaporate.The relative humidity governs how quickly evaporation occurs.

- High relative humidity = low evaporation rate.
- Low relative humidity = high evaporation rate.

When the A/C system removes moisture from the air, the relative humidity in the passenger compartment decreases. By reducing the relative humidity, the A/C system increases the rate at which the moisture on passengers’ skin will evaporate.

- Temperature in the range of 70°F to 80°F (21°C to 27°C).
- Relative Humidity of about 45% to 50%.

Air pollution is another valid concern that automotive engineers must address in their effort to control the climate of our passenger compartments. In order to effectively limit the presence of undesirable allergens like dust, pollen, smoke, chemical fumes and other impurities, high performance micro filters have been developed and are currently used.

- Abundant air circulation (the more air the cooler the sensation).
- Adequate air filtration.

Principals of Heating and Refrigeration

Heat and Cold Explained

From a physics point of view there is no cold but rather only heat at different temperature levels. There is no more heat at -273°C (-459.4°F), or absolute zero.

For a person to experience the feeling of cold, heat must be removed from his/her environment.

When you place your hand on a block of ice, the heat is transmitted from the hand to the block of ice. This continues until a heat balance or thermal equilibrium takes place between the hand and block of ice. Seen from a human point of view, both objects are then equally cold.

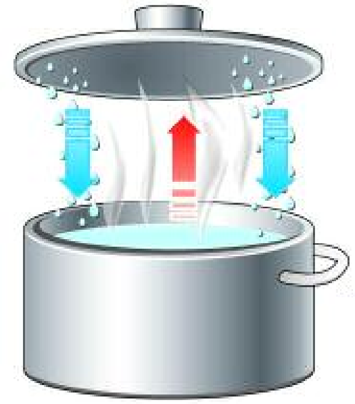
Note: Heat always travels from the higher to the lower temperature level and never the other way round.

A simple example of taking heat from the surroundings is the use of volatile liquids. These are substances that readily change from the liquid to the gaseous state, or they evaporate. When such a liquid (Cologne) is applied on the skin at room temperature, it evaporates and becomes a gas, as a result a cool sensation is experienced. Obviously, heat is taken away from the skin during the transition from a liquid to the gaseous state.

Note: To generate cold it is therefore necessary to allow a liquid that readily evaporates to boil and then evaporate away and thus take heat with it.

Steam behaves in precisely the opposite way as the procedure described above when it cools or is cooled:

- While boiling, the water vapor collects on the lid of the pot (see illustration), where it cools down and becomes liquid again (condensation droplets).
- Warm moist air in the vehicle interior collects on the cold windows where it cools down and settles in the form of moisture on the windows or (condensation mist).



Condensation and Evaporation

A gaseous substance that cools down becomes liquid again as from a certain temperature. All liquids can evaporate by the application of heat. On reaching boiling point, the further application of heat leads to evaporation of the liquids.

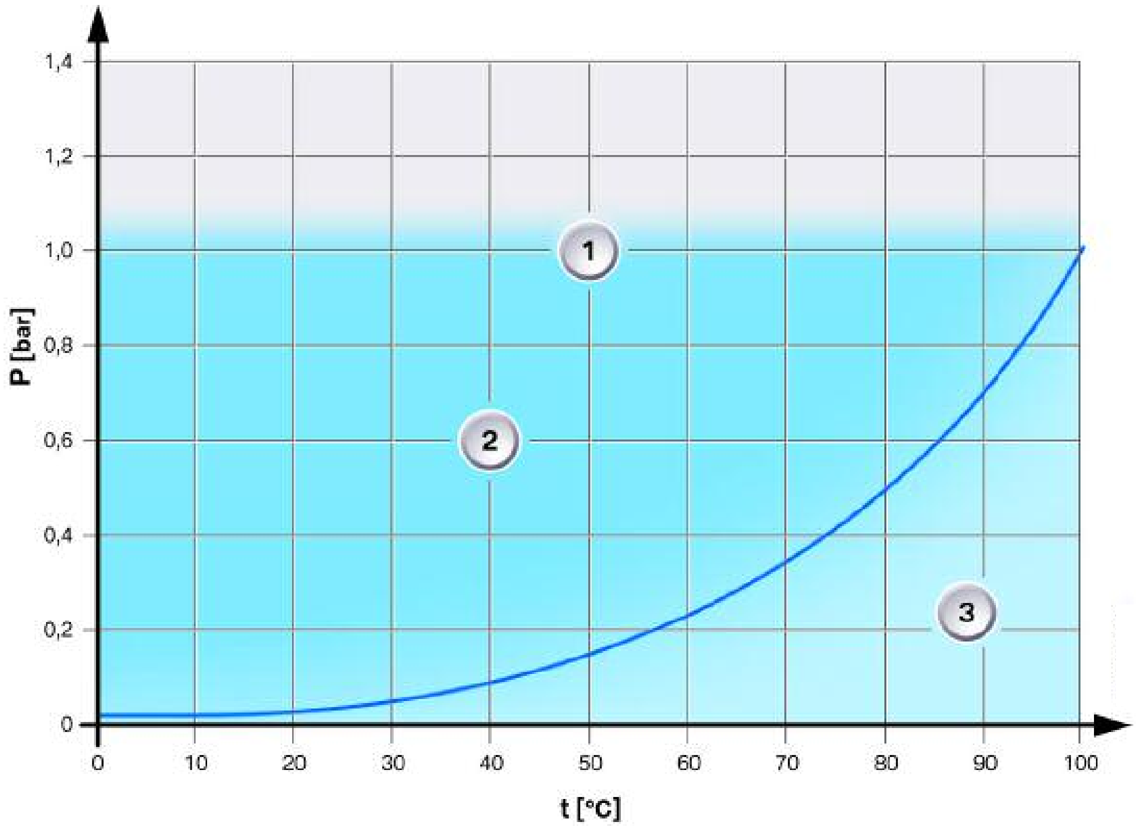
To reach boiling point, water is heated to a temperature of 100°C at standard air pressure. The further application of heat does not change the temperature of the water but rather it causes the water to evaporate.

Evaporation of Water

The evaporation of water at different pressures and temperatures is represented simply by the following steam-pressure curve. A simple orientation aid is the known boiling point of water. At standard ambient pressure 14.5psi (1 bar) water evaporates at a temperature of 100°C (212°F).

Note: 1 bar = 14.5psi = 100Kpa

1 Atmosphere = 1.01325 bar = 14.7psi



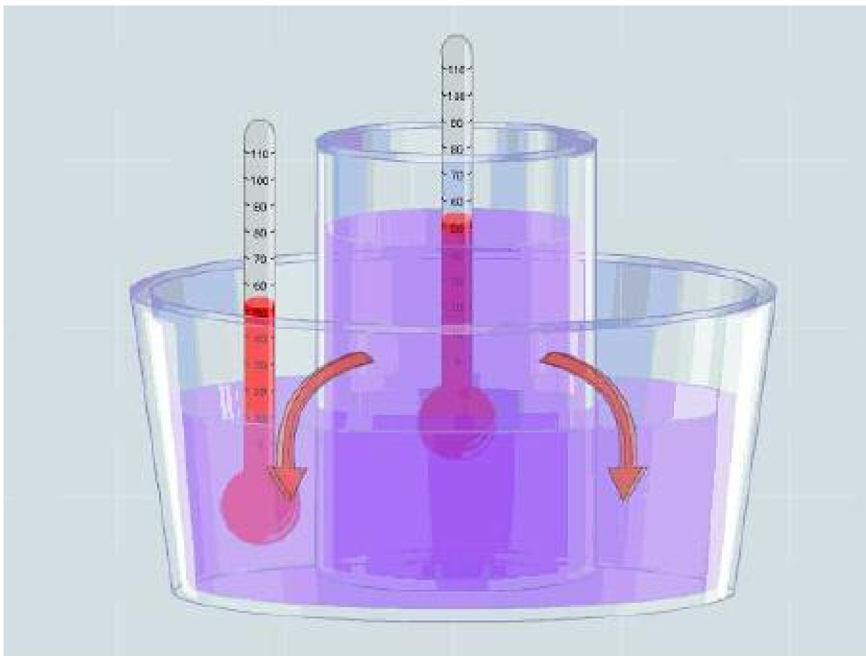
Index	Explanation
1	Standard atmospheric pressure approx. 1 bar
2	Liquid (water)
3	Gaseous (water)

The curve shows that water evaporates at room temperature of approx. 20°C at an ambient pressure of 0.023 bar (23 mbar), i.e. under partial vacuum. 1 bar = 1000 mbar. The pressure gauges used in technical applications are mostly calibrated to 0 bar at ambient pressure and do not show the physically correct pressure of 1 bar.

- All pressure/temperature ratios above the curve signify water in a liquid state.
- All pressure/temperature ratios below the curve signify water in a gaseous state.

Heat Transfer

Everything is made up of atoms combined to form molecules and these live in very close proximity. There is interaction between them in the form of vibrations. These vibrations can't be felt but can always be measured in the form of heat as it flows from a warm object to a cold object.



We put a glass of hot water in a bowl of warm water and:

- The water in the glass got colder
- The water in the bowl got hotter
- Eventually the water in the bowl will equal the water in the glass

From this experiment we can conclude that:

- Cooling is the dissipation of heat energy
- Cooling occurs by way of heat exchange
- Heat always passes from a higher to a lower temperature level

Heat transfers from molecule to molecule in three methods: convection, conduction and radiation.

- Convection is the transfer of heat via a medium, either gas or liquid. Hot objects warm up the medium surrounding them and thus any cooler object in their proximity like food in an oven or a spoon in hot coffee.
- Conduction is the transfer of heat by direct physical contact between objects like a pot on a stove top or an iron on an ironing board.
- Radiation takes place when an object is warmed by the exposure to infrared rays, like the rays of the Sun, warm everything in their path even though it is millions of miles away.

Note: Radiation is one of the major factors affecting the performance of automotive AC systems as sunlight penetrates the vehicle's glass windows.

Sensible and Latent Heat

Liquids and gases contain two types of heat: Sensible and Latent heat. Sensible heat can be felt or sensed. Latent heat is called hidden heat. Liquids and gases contain Latent heat because it is absorbed to produce a change of state.

Types of Latent Heat

- Latent heat of fusion or freezing (to change from a liquid to a solid by giving up heat).
- Latent heat of vaporization (to change from liquid to a gas by absorbing heat).
- Latent heat of condensation (to change from a gas to a liquid by giving up heat).
- Latent heat of melting (to change from a solid to a liquid by absorbing heat).

Change of State

Many substances are known in three states of aggregation. Example: water, solid, liquid and gaseous. The cooling process is based on this natural law. Efforts to achieve cooling go back a long way. One of the first food cooling processes was to store food in the "ice box". Heat is taken from the food by the ice = (water in solid state of aggregation). Consequently, the food cools down. The ice melts and assumes a different state of aggregation, (it becomes liquid). If further heat were applied to the water it would boil and evaporate. The gaseous state of aggregation is then reached. The gaseous substance can turn to liquid again by cooling and revert to a solid state by further cooling. This principle can be applied to almost all substances.

First Natural Law

Note: "Energy can neither be created nor destroyed, but can be converted from one type to another"

- A substance takes up or absorbs heat during the transition from the liquid to the gaseous state.
- A substance gives off heat during the transition from the gaseous to the liquid or solid state.
- Heat always flows from the warmer to the colder substance.

The effects of the heat exchange where a material changes its state under certain preconditions are utilized and technically implemented in air conditioning technology.

At the Solidification point: e.g. water becomes ice.

At the Boiling point: e.g. water becomes steam.

Ice (solid water)

Ice absorbs heat and becomes liquid.

Water absorbs heat and becomes vapor (gaseous)

Heat and Temperature

Heat is the energy that describes the state of a body. The temperature depends on the intensity of the movement of its atoms or molecules.

Heat is no longer present at -273.15°C = 0° Kelvin. This value is known as absolute zero where molecules and atoms cease to move and the body no longer has heat or thermal energy.

Depending on the thermal conductivity, temperature is perceived differently on contact with a body so that temperature must therefore be measured with a thermometer.

When two objects at different temperatures move, the heat always flows from the warmer to the colder object. The warmer object cools down, the colder object heats up until both objects reach the same temperature. Here, heat is transported until a state of thermal equilibrium is reached.

Generating cold therefore means removing heat. From a thermodynamics point of view, the term cold is not used as long as the temperature of the room, material or body is above absolute zero.

There are various methods of generating cold (low temperature):

- Adiabatic cooling (cooling effect by the movement of air over a moist surface).
- Absorption method (giving off energy to a liquid to change the state of aggregation).
- Peltier cooling (electric cooling method).

BTUs and Calories

Heat is measured in British Thermal Units (BTUs) and calories.

- BTU - amount of heat energy required to raise one pound of water one degree Fahrenheit.
- Calorie - amount of heat energy required to raise one gram of water one degree Celsius.

It is in the interest of the user to apply the least possible amount of energy to achieve high refrigerating capacities. In motor vehicle air conditioning systems, this is achieved by the cold vapor compression method known as a compression-type refrigerating system.

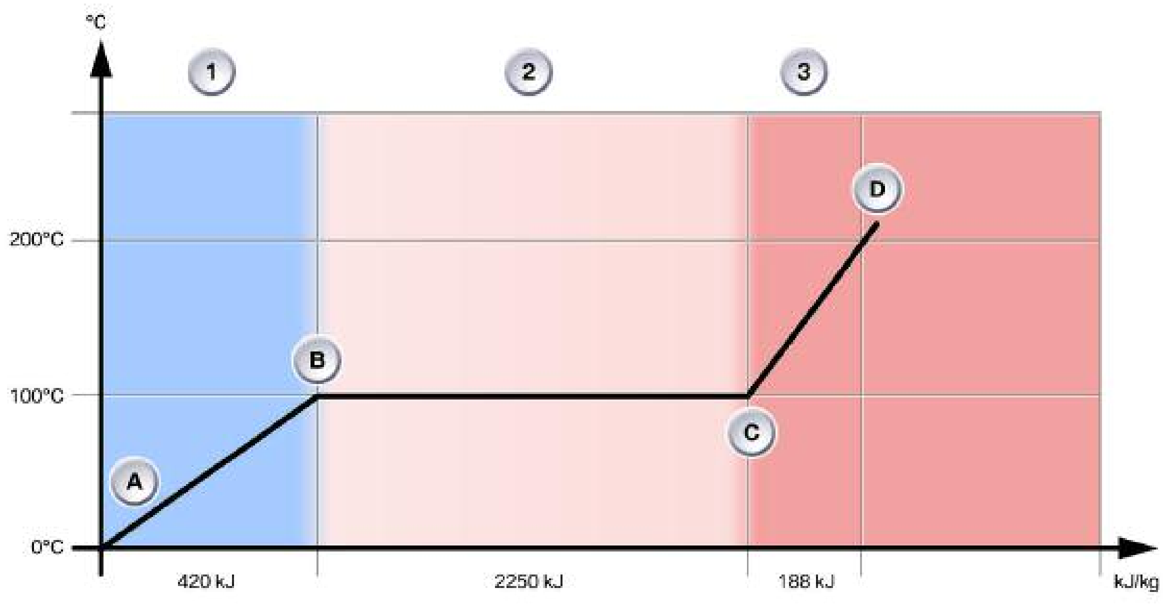
The quantity of heat corresponds to the thermal energy contained in a body without thermal reaction. It is measured in Joules (formerly Calories).

The quantity of heat required to heat 1 kg of water:

Water from	0°C - 100°C	420 kJ
Evaporation at	100°C	2257 kJ
Water vapor (steam) from	100°C - 200°C	188 kJ

The *specific heat* is the quantity of heat required to heat a kilogram of a certain substance by 1°C without a change in phase or state occurring.

The *evaporation or vaporization heat* is the quantity of heat required to change 1 kg of a substance from a liquid to a vapor state.

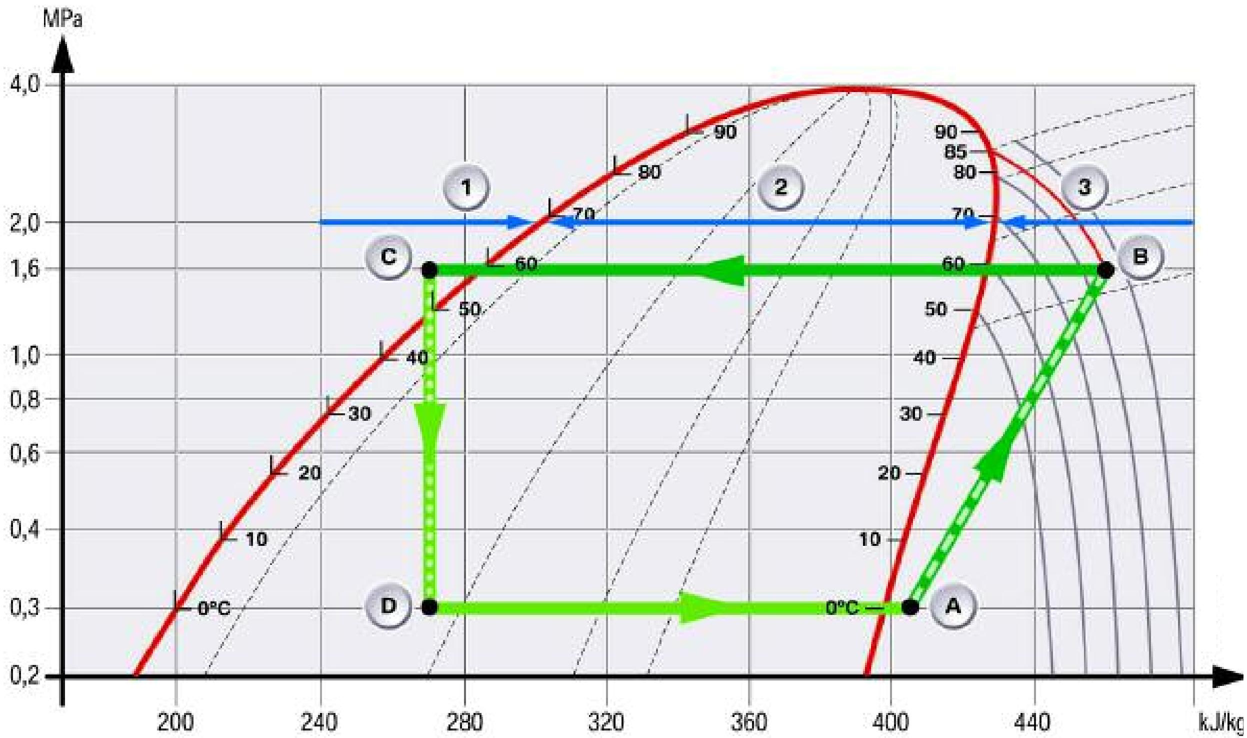


Index	Explanation	Index	Explanation
1	Liquid	A-B	The liquid is heated from 0°C to100°C. The first vapor (steam) bubbles occur at point B. 420 kJ of heat are required up to this point.
2	Two Phase liquid/Gas bubbles	B-C	The liquid changes into saturated vapor (steam). The liquid is completely evaporated at point C. The temperature is constant during this phase change and an energy supply of 2250 kJ is required.
3	Gas	C-D	The vapor is heated further. 188 kJ of heat must be added to increase the temperature of the vapor by 100°C. 1.88 kJ of heat are required to heat up 1 kg of water by 1°C. Specific heat of steam.
A	Point A the sub-cooling of a liquid = cooling below the point of condensation or Dew Point.	D	At point D, the superheated vapor (steam) as a total thermal (heat) energy of 2858 kJ (enthalpy) = heat content of a substance.

As we analyze the chart we can see:

- Water boils at a temperature of 100°C at 1 bar ambient pressure
- Despite applying more heat, a further increase in temperature is not possible until the entire quantity of water is evaporated.
- This thermal energy enables the phase transition.
- At point A sub-cooling of a liquid = cooling below the point of condensation or Dew Point.
- At point D superheated vapor (steam) by heating above the temperature of boiling (Water).

At a temperature of 100°C, water is in a liquid and gaseous state, known as the two-phase zone. Once all the water has been evaporated, the further application of energy results in heating the steam above 100°C. The specific heat of the steam is the characteristic value for this further heating process.

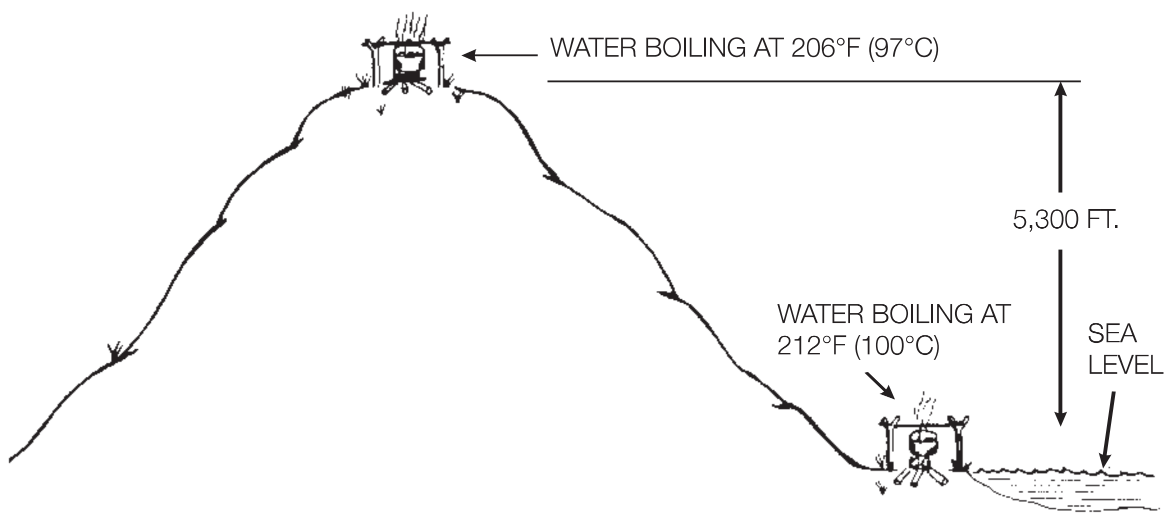


Graphical Explication of the Refrigerant Cycle

Index	Explanation
1	Liquid
2	Two Phase Zone (Liquid/gas)
3	Gas
A-B	Compression in the compressor, gaseous, high pressure, high temperature
B-C	Compression in the compressor, gaseous, high pressure, high temperature
C-D	Expansion = abrupt pressure relief causes evaporation
D-A	Evaporation process in the evaporator. Transition from liquid to gaseous state, low pressure.

Effects of Pressure

The boiling point of a liquid rises as altitude increases and vise versa.



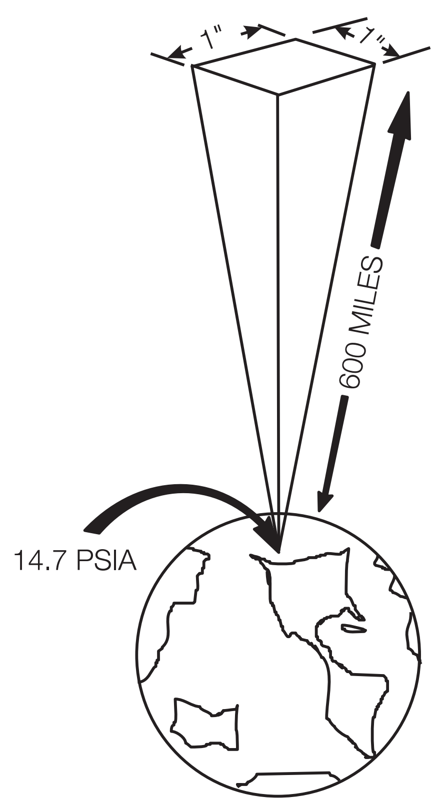
The Boiling Point of Water at 5,300 Feet

Water boils at sea level at 100°C (212°F) and as atmospheric pressure drops so does the boiling point.

Atmospheric pressure is 14.7psi (absolute) at sea level and gradually lower at higher attitudes.

Imagine the pressure in the atmosphere represented as a one inch square, 600 mile high column of air; the higher on this column we go, the lighter the air becomes and the lower the pressure.

Note: Absolute pressure takes into account that there is 14.7psia of atmospheric pressure at sea level and this is calibrated as 0 pressure on all gauges, so any pressure below the ZERO is vacuum and above is absolute pressure.



Of course, you don't notice the 14.7 psi pressing in on everything, and air pressure gauges are calibrated to read 0 psi at atmospheric pressure.

But this atmospheric pressure exists, and you can feel its effects, particularly at higher elevations; for example, if you exercise vigorously, at a high elevation, you become winded more quickly. Humans as well as machines feel the effects of the thinner air at altitudes.

A soccer player that is accustomed to playing at sea level will feel fatigued and run down in a very short time at high altitudes like in Quito, Ecuador at 9,200 feet or La Paz, Bolivia at 11,811 feet.

Vehicles also suffer the dramatic effects of altitude which robs them of power. The development of electronic fuel injection and forced induction made it possible to compensate for these adverse conditions.

In an air conditioning system, the pressure in the evaporator is low, so that all the refrigerant vaporizes. The pressure in the condenser is high, so that all the refrigerant readily changes state to a liquid.

Raising the pressure of a vapor raises its temperature; lowering the pressure decreases its temperature.

In an air conditioning system, a compressor is used to increase the pressure of the refrigerant; this raises its temperature. The refrigerant vapor entering the condenser is hot.

In BMW air conditioning systems, an expansion valve is used to lower the pressure of the refrigerant; the refrigerant in the evaporator is cold.

Automotive A/C systems are designed to operate at pressures that keep the refrigerant at the optimum temperature for taking heat out of the passenger compartment.

Pressure and Boiling Points

The boiling point of a liquid changes if the pressure above it changes. All liquids behave in the same way.

- Boiling point of H_2O/water = 100°C (212°F)
- Boiling point of machine oil = 380 to 400°C (716 to 752°F)

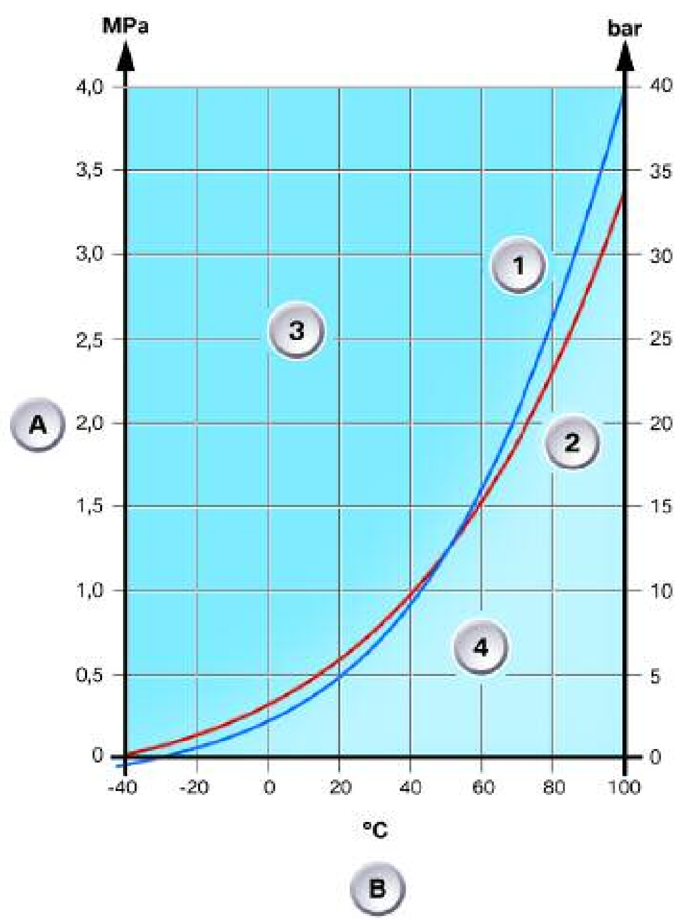
We know that water boils (becomes steam) at lower temperatures, the lower the pressure. Air conditioning systems in motor vehicles also make use of the evaporation process. A substance with a low boiling point is used for this purpose. It is known as refrigerant.

- Boiling point of refrigerant R12 = -29.8°C (-21.6°F)
- Boiling point of refrigerant R134a = -26.5°C (-15.7°F)

(The boiling point of liquids specified in tables always refers to an atmospheric pressure of 0.1 MPa = 1 bar)

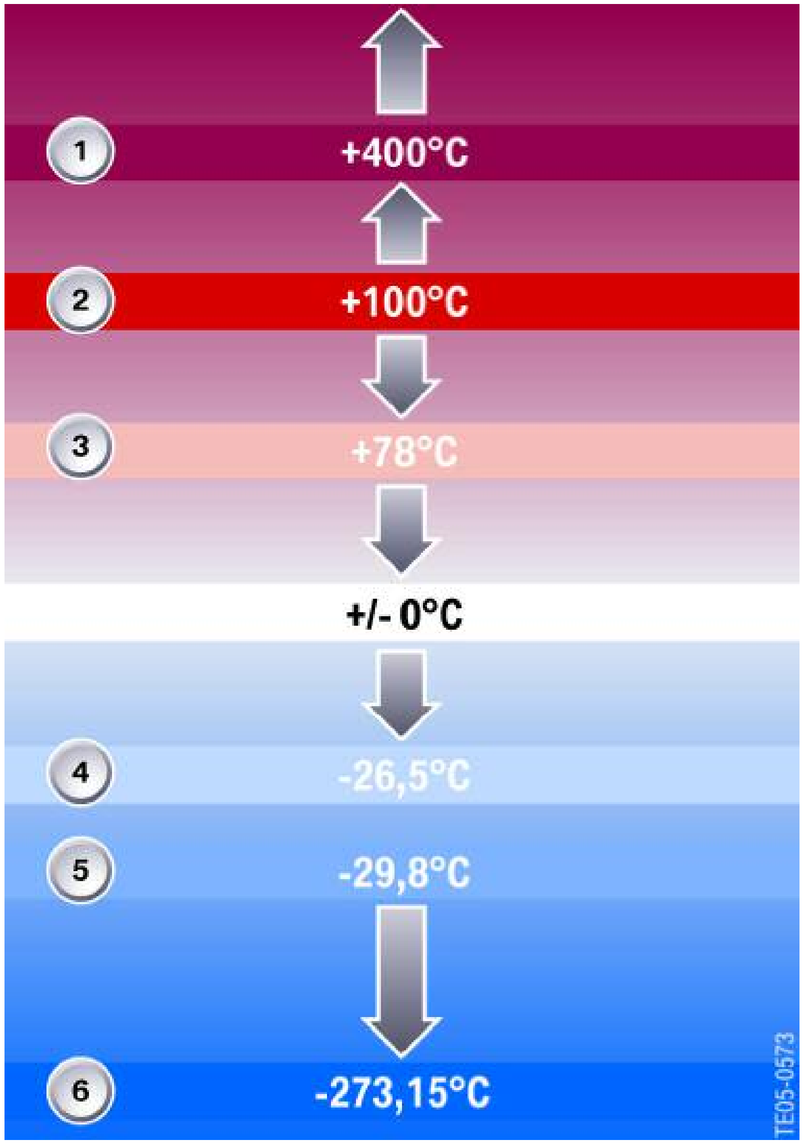
The following points can be established based on the vapor-pressure curves for the two refrigerants R134a and R12 (R12 is no longer used).

At a constant pressure, the gas becomes liquid by reducing temperature (in the refrigerant circuit of the air conditioning system, this takes place in the condenser) or by reducing pressure the refrigerant changes from the liquid to the gaseous state (in the circuit of the air conditioning system, this takes place in the evaporator).



Index	Explanation
A	Pressure
B	Temperature
1	R134 a
2	R12
3	Liquid
4	Gaseous

Boiling Point of Various Substances



Index	Explanation
1	Machine oil
2	Water
3	Spirits
4	R134a
5	R12
6	Absolute 0